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# **An Analysis of the Crash Experience of Light Trucks Equipped with Antilock Braking Systems**

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16. Abstract <p>Using data from FARS and Florida, Maryland, Michigan, and Missouri, four ABS-relevant crash types were identified as follows: (1) rollovers, (2) side impacts with parked vehicles or fixed objects, (3) frontal impacts with parked vehicles or fixed objects, and (4) frontal impacts with another motor vehicle in transport. The light truck experiences in these four crash types were compared to a control group of crashes that are not expected to be affected by the presence of ABS. Detailed findings are provided for each type of ABS system, for the four individual crash types, and on favorable vs. unfavorable road surfaces. The following findings were noted:</p> <ul style="list-style-type: none"> <li>o Significant reductions in nonfatal rollover crashes and side impacts with fixed objects/parked vehicles were associated with the presence of RWAL;</li> <li>o A significant reduction in nonfatal rollover crashes was associated with the presence of AWAL;</li> <li>o The reductions in nonfatal crashes did not extend to fatal crashes, in which no significant reductions associated with the RWAL or AWAL were found;</li> <li>o Significant increases in "did not stop in time" nonfatal and fatal crashes were found, associated with the presence of RWAL; and</li> <li>o The relatively small sample size available for AWAL systems made it more difficult to detect significant differences in crashes.</li> </ul>					
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## **Executive Summary**

Data from NHTSA's Fatal Accident Reporting System, supplemented by state crash files, were used to analyze the crash experience of antilock brake-equipped (ABS) and non-ABS-equipped light trucks. State crash files for Florida, Maryland, Michigan and Missouri were chosen for analysis because these states collect and report, on their automated files, the vehicle identification number for crash-involved vehicles, an important characteristic for identifying specific makes/models and model years.

Four ABS-relevant crash types were identified as follows:

- (1) rollovers,
- (2) side impacts with parked vehicles or fixed objects,
- (3) frontal impacts with parked vehicles or fixed objects, and
- (4) frontal impacts with another motor vehicle in transport.

Crash types (1) and (2) generally involve driver loss of control, wherein ABS is expected to increase the vehicle's directional stability, allowing the driver to maintain greater control and remain on the roadway. Crash types (3) and (4) generally involve driver loss of control or the presumption that the driver did not apply the brakes or was unable to stop in time. The light truck experiences in these four crash types were compared to a control group of crashes that are not expected to be affected by the presence of ABS.

Two ABS systems were analyzed separately: rear-wheel antilock (RWAL) and all-wheel antilock (AWAL) braking systems. RWAL is much more prevalent in the on-road light truck fleet, with AWAL-equipped light trucks becoming available only during the last few years. While RWAL systems control only the rear wheels' braking, increasing directional stability, AWAL systems, operating on all four wheels, should increase directional stability and provide benefits in stopping distance on low friction surfaces experienced during rain and snow.

The report provides detailed findings for each type of ABS system, for the four individual crash types, and on good vs. bad road surfaces. The following findings were noted:

- o Significant reductions in nonfatal rollover crashes and side impacts with fixed objects/parked vehicles were associated with the presence of RWAL;
- o A significant reduction in nonfatal rollover crashes was associated with the presence of AWAL;
- o The reductions in nonfatal crashes did not extend to fatal crashes, in which no significant reductions associated with the RWAL or AWAL were found;
- o Significant increases in nonfatal and fatal frontal crashes with another vehicle in transport were found, associated with the presence of RWAL; and
- o The relatively small sample size available for AWAL systems made it more difficult to detect significant differences in crashes.



## INTRODUCTION

Section 2507 of the Highway Safety Act of 1991 (the Act) directs NHTSA to initiate rulemaking to consider the need for any additional brake performance standards, including antilock braking systems (ABS) for all passenger vehicles, i.e., passenger cars, light trucks, sport utility vehicles and vans weighing less than 10,000 pounds. The Act also directs NHTSA to publish an Advance Notice of Proposed Rulemaking (ANPRM) by December 31, 1993 regarding the upgrade of braking standards. NHTSA's determination of the viability of upgrading braking standards was directed to include consideration of a mandatory ABS requirement for all passenger vehicles.

Automobile manufacturers have offered ABS to consumers either as a standard feature or as an option on millions of passenger cars and light trucks since approximately 1985. Most consumers appear to be knowledgeable about the availability of ABS-equipped vehicles, and many have chosen to purchase vehicles equipped with ABS. Manufacturers have actively advertised the availability of ABS on specific vehicle make/models and their potential safety benefits. In addition, several insurance companies offer discounts in premiums to consumers for ABS-equipped vehicles.

The objective of ABS is to automatically modulate braking pressure to prevent the vehicle's wheels from locking during braking. By preventing wheel lockup, ABS allows drivers to control their vehicles even in panic braking situations. Two types of ABS systems are presently available, all-wheel (AWAL) and rear wheel (RWAL). Passenger cars typically are equipped with AWAL, which is designed to keep all wheels of the vehicle rolling in an emergency braking situation. This allows the driver to properly steer the vehicle during the emergency situation and on some road surfaces, is intended to shorten the stopping distance. Most light trucks and vans with ABS are equipped with RWAL. RWAL prevents the rear wheels of these vehicles from "locking up" during emergency braking situations. Preventing lock up is designed to alleviate difficulties in directional control, typically experienced by light trucks and vans in emergency braking maneuvers. An increasing number of light trucks and vans are being equipped with AWAL. While more light trucks and vans are being equipped with AWAL, the total population of all registered light trucks and vans on the road today with AWAL remains very small. In this study, AWAL represents the portion of light trucks and vans equipped with this type of ABS.

Earlier work to study ABS effectiveness was conducted by NHTSA's Office of Plans and Policy<sup>1</sup>. This study contained an analysis of crash data along with a discussion of NHTSA's stopping tests involving ABS-equipped vehicles. The focus of the current analysis is to determine the impact of ABS on specific types of crashes, similar to a portion of the

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<sup>1</sup> Kahane, Charles J., Ph.D., *Preliminary Evaluation of the Effectiveness of Rear-Wheel Antilock Brake Systems for Light Trucks*, [December 1993].

work conducted by Kahane (1993), thereby increasing the Agency's knowledge regarding the effectiveness of ABS in particular crash scenarios.

## **DATA SOURCES, SELECTING CRASHES AND IDENTIFYING VEHICLES**

Data from NHTSA's Fatal Accident Reporting System (FARS) were used to analyze the crash experience of ABS-equipped and non-ABS-equipped light trucks in the study. FARS began in 1975 and contains a census of the most severe traffic crashes, i.e., those resulting in a fatality. A crash is included in FARS when it involves a motor vehicle traveling on a trafficway open to the public and results in the death of an occupant of a vehicle or a nonmotorist within 30 days of the crash. FARS data for calendar years 1989-1993, the five most recent available years, were selected for this analysis. It was felt that the five most recent years of data would provide a sufficiently large sample of crashes involving both ABS- and non-ABS-equipped vehicles.

In addition to data from FARS, the three most recent years available of state crash files (1989-1991) for Florida, Maryland, Michigan, and Missouri were chosen for analysis. The files for Florida, Maryland, Michigan, and Missouri contain data on all applicable police-reported crashes that occurred in these states, ranging in severity from property-damage-only to fatal. In addition, these states collect and report in their automated files the vehicle identification number (VIN) of crash-involved vehicles. This characteristic was important in selecting the state files that would be used in the analysis, as VIN was used to identify specific makes and models of light trucks and vans that were equipped with ABS and to identify comparable non-ABS vehicles.

Once FARS and the specific state files were selected for use in the analysis, the next step was to prepare each of these data files into treatment groups and a control group. The objective was to separate those crashes in which the vehicle involved would be affected by the presence of ABS (i.e., treatment groups) from those crashes in which the vehicles involved would not be affected by ABS (i.e., a control group). With this view in mind, certain crash types considered to be "ambiguous" were deleted. Ambiguities in characterizing crashes and the vehicles involved in these crashes arose in following areas: crash factors, driver factors, environmental factors, and vehicle factors.

**Crash factors:** Crashes were considered ambiguous if, for example, it was uncertain whether ABS would have been beneficial in either avoiding the crash or reducing the severity of the crash. These ambiguous crashes included all first-event crashes with nonmotorists, animals, trains and other moving or nonfixed objects. Sideswipes in multiple-vehicle collisions, head-on collisions and collisions with a vehicle on another roadway were also eliminated, as well as crashes in which the manner of collision was either unknown or characterized as "front-rear". Front-rear crashes are those in which the vehicles in question have at least two impacts, one in front and one in the rear, as in a "pile-up" crash.

**Driver factors:** Vehicles with an alcohol-impaired driver were also eliminated from the treatment groups, as it was considered questionable whether or not a driver, under the influence of alcohol, would be able to use ABS properly in an emergency crash situation.<sup>2</sup>

**Environmental factors:** Crashes where the road condition (i.e., wet vs. dry, paved vs. unpaved) was unknown were deleted since one goal of the study was to determine the effect of ABS separately for favorable ("good", i.e., paved, free of debris, dry) and unfavorable ("bad", i.e., wet, snowy, icy, gravel, unpaved) road conditions.

**Vehicle factors:** Certain vehicles (e.g., General Motors K10/15 and T10/15 pickups) were dropped if these crashes occurred on an unpaved or nondry road surface. This was based on the assumption that these vehicles may have been operating in the four-wheel drive configuration, thereby disabling rear-wheel antilock brakes (RWAL).

Data for the remaining crashes were divided into four separate *treatment* groups as follows. Each of the four types of ABS-relevant crashes were defined according to the first event:

- (1) rollovers (ROLL);
- (2) side impacts with parked vehicles or fixed objects (SIDE), both considered "loss of control" situations;
- (3) frontal impacts with another motor vehicle in transport (FRONT); and
- (4) frontal impacts with parked vehicles or fixed objects, i.e., "run-off-the-road" (ROR) situations, in which it is unclear whether either inability to stop and/or loss of control were major crash factors.

The vehicles involved in these four treatment groups of crashes were considered to represent those for which there would be potential safety benefits of ABS.

The vehicles remaining in each of the data sets after the treatment group vehicles and ambiguous crashes were removed comprised the control group. The crash involvement experience for each of the four treatment groups was analyzed and compared with the experience for the control group of crashes. Vehicles remaining in the control group consisted of those with rear damage only, e.g., backed-into crashes, vehicles in multiple-vehicle accidents (other than those in FRONT crashes) and nonrollover noncollisions.

Appendix A presents a schematic that depicts the allocation of crashes from FARS and the

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<sup>2</sup> A separate analysis including vehicles operated by alcohol-impaired drivers was conducted to determine if the findings of ABS effectiveness would be greatly affected. The results including alcohol-impaired drivers were almost identical to the results without these drivers.

state files into the four treatment groups and the control group, along with a listing of those ambiguous and other crashes that were eliminated from consideration. Appendix B presents tables of the distribution of vehicle types and the proportion of ABS-equipped vehicles for each of the four treatment groups and the control group for the FARS and state files.

Once the vehicles in FARS and the state files were separated into treatment and control groups, it was necessary to identify which specific vehicle makes and models were equipped with ABS vs. those that were not. This process was labor intensive and required collaboration among staff from various NHTSA offices. Information from vehicle manufacturers and other informal sources was used to arrive at the final list of vehicles identified with or without ABS. The lists of vehicles are presented in Appendix C.

## ANALYTICAL METHOD

A crash was considered ABS relevant if it might have been affected by the presence of ABS. Obviously, there is no direct way to count the crashes that were prevented, nor is there any way to determine if ABS was activated during the pre-crash maneuver or if any braking actually was attempted. The basic approach, therefore, was to study the change in the proportion of crashes in which ABS had the *potential* to prevent the crash (that is, in each of the treatment groups representing various crash types), assuming that the presence or absence of ABS does not affect the occurrence of nonrelevant crashes. The analytical method chosen for this study also controls for some characteristics of the drivers along with environmental and vehicle factors.

Separate analyses were conducted for light trucks and vans with rear-wheel antilock brakes (RWAL LTV's) and light trucks and vans with all-wheel ABS (AWAL LTV's). As stated, four types of relevant crashes, also called treatment groups, were considered. These treatment groups were rollover (ROLL), side impact with a fixed object (SIDE), frontal impact with a fixed object (i.e., run-off-the-road crashes, ROR) and involvement in a two-car crash as the striking vehicle (i.e., driver "did not stop in time" crashes or FRONT). For each vehicle type, RWAL or AWAL, separate analyses were conducted for crashes that occurred on favorable road conditions, i.e., "good" and unfavorable road conditions, i.e., "bad".

The basic technique was to consider the crash data as each observation corresponding to a vehicle that had been in a crash. Logistic regression<sup>3</sup> was used to test the effect of ABS on the probability that the crash was relevant, while controlling for other factors. This

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<sup>3</sup> Hosmer, D. and Lemeshow, S., *Applied Logistic Regression*, John Wiley and Sons Publications, 1989.

technique has been successfully used in other NCSA and NHTSA studies.<sup>4,5</sup>

Estimating the impact of ABS in reducing relevant crashes could be confounded by factors related to the driver, environment, crash, or other circumstances. To accurately estimate the impact of ABS, therefore, variables were included in the logistic regression to control for those factors, other than ABS, which could influence the proportion of relevant crashes. For example, if ABS-equipped pickup trucks are more likely to be driven by younger males than by other segments of the driving population, then driver and vehicle characteristics could confound estimating the impact of ABS. As a result, the age and the sex of the driver, whether or not the crash occurred on a curved road segment (thereby increasing the difficulty in maneuvering to avoid a crash), whether the crash occurred in a rural vs. an urban setting, and the age of the vehicle were chosen for inclusion in the logistic regression model.

For each of the four states and FARS, for each type of surface ("good" or "bad"), for each category of vehicle (RWAL and AWAL) and for each of the four types of treatment group crashes, a logistic regression model was estimated of the form:

$\text{logit}(p) = \text{AGE YOUNG MALE CURVED ABS RURAL VEH\_AGE}$ , where:

- **p** is the probability of an ABS-relevant response,
- **AGE** is the age of the driver,
- **YOUNG** is an indicator variable that takes the value 1 if the driver is under 25, 0 otherwise,
- **RURAL** was not available in Missouri and an indicator variable for speed limit of at least 45 mph was substituted.

For RWAL LTV's, the variables:

- **SPORT** (sports utility vehicle indicator), and
- **PICKUP** (pickup truck indicator) were also included in the model.

Each of these models was run a second time with only those predictors that were statistically significant; ABS was always retained. This resulted in a final estimate of the coefficient for ABS and its standard error for each of the analyses, as shown in Tables 1A and 1B. Table entries represent the change in the log odds ratio of an ABS-relevant to an ABS-nonrelevant crash in the presence of an ABS-equipped vehicle. **Negative coefficients indicate a reduction in crashes associated with the presence of ABS.**

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<sup>4</sup> Klein, T. M., Hertz, E., and Borener, S., *A Collection of Recent Analyses of Vehicle Weight and Safety*, U. S. Department of Transportation, DOT-HS-807-677, May 1991.

<sup>5</sup> Klein, T. M., *A Statistical Analysis of Vehicle Rollover Propensity and Vehicle Stability*, SAE Technical Paper Series 920584, Society for Automotive Engineers, 1992.

**TABLE 1-A**  
**Summary of Logistic Regressions for**  
**Rear Wheel Antilock-Equipped LTVs**

*Rollover Crashes*

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	0.0640	0.1091	0.0797	0.1792
FLORIDA	-0.6261 *	0.1113	-0.7861 *	0.1696
MARYLAND	-0.5738	0.3679	-1.4707 *	0.5552
MICHIGAN	-0.5977 *	0.0751	-0.3420 *	0.0486
MISSOURI	-0.6182 *	0.0992	-0.2467 *	0.1174

*Side Impact Crashes w/Parked Vehicle or Fixed Object*

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	0.0138	0.1531	0.2057	0.1996
FLORIDA	-0.3658 *	0.1013	-0.7740 *	0.1919
MARYLAND	0.1777	0.1571	-0.2069	0.1379
MICHIGAN	-0.1001	0.0801	-0.3366 *	0.0608
MISSOURI	-0.1932	0.1050	-0.3241 *	0.1231

\* Indicates Statistical Significance at the  $\alpha = 0.05$  level, two-tailed test  
 NC Non-Convergence of Logistic Regression

**TABLE 1-A - Continued**  
**Summary of Logistic Regressions for**  
**Rear Wheel Antilock-Equipped LTVs**

*Front Impact Crashes w/ Another Vehicle in Transport*

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	0.2411 *	0.0478	0.3930 *	0.0911
FLORIDA	0.1062 *	0.0218	0.0648	0.0460
MARYLAND	0.1172 *	0.0479	0.1196	0.0745
MICHIGAN	0.0689 *	0.0217	0.1535 *	0.0295
MISSOURI	0.1238 *	0.0387	0.2705 *	0.0637

*Front Impact Crashes w/ Parked Vehicle or Fixed Object*

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	0.0921	0.0776	0.1500	0.1539
FLORIDA	-0.0388	0.0534	-0.0692	0.0946
MARYLAND	0.1784	0.1351	0.1749	0.1629
MICHIGAN	0.0445	0.0582	-0.0224	0.0364
MISSOURI	-0.0354	0.0548	-0.1003	0.0750

\* Indicates Statistical Significance at the  $\alpha = 0.05$  level, two-tailed test  
 NC Non-Convergence of Logistic Regression

**TABLE 1-B**  
**Summary of Logistic Regressions for**  
**All Wheel Antilock-Equipped LTVs**

*Rollover Crashes*

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	0.1564	0.2261	0.0388	0.5176
FLORIDA	-0.5137	0.6115	NC	NC
MARYLAND	NC	NC	NC	NC
MICHIGAN	-0.7207	0.4448	-0.3764	0.2071
MISSOURI	-0.7032	0.6535	0.0660	0.8134

*Side Impact Crashes w/Parked Vehicle or Fixed Object*

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	0.6108	0.3664	-1.1100	1.0379
FLORIDA	-0.6547	0.7164	0.2587	0.7511
MARYLAND	0.1258	0.7551	NC	NC
MICHIGAN	0.1620	0.3129	-0.9659 *	0.3373
MISSOURI	-0.3527	0.6087	0.2656	0.7693

\* Indicates Statistical Significance at the  $\alpha = 0.05$  level, two-tailed test  
 NC Non-Convergence of Logistic Regression

**TABLE 1-B - Continued**  
**Summary of Logistic Regressions for**  
**All Wheel Antilock-Equipped LTVs**

*Front Impact Crashes w/ Another Vehicle in Transport*

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	-0.1093	0.1456	-0.4696	0.3225
FLORIDA	0.1129	0.1158	-0.0018	0.2535
MARYLAND	0.4867 *	0.2464	-0.3065	0.5440
MICHIGAN	0.1266	0.0688	-0.2602 *	0.0948
MISSOURI	0.0525	0.1687	-0.4745	0.3604

*Front Impact Crashes w/ Parked Vehicle or Fixed Object*

Database	On Good Surfaces		On Bad Surfaces	
	ABS Coeff.	Std. Error	ABS Coeff.	Std. Error
FARS	0.0004	0.2339	-1.1878	0.7457
FLORIDA	0.1328	0.3087	-0.7150	0.7339
MARYLAND	0.7611	0.5611	-0.2455	1.0790
MICHIGAN	-0.1756	0.2279	-0.4626 *	0.1775
MISSOURI	-0.8599	0.4774	-0.5094	0.6741

\* Indicates Statistical Significance at the  $\alpha = 0.05$  level, two-tailed test  
 NC Non-Convergence of Logistic Regression

It appears reasonable to assume that the effects of ABS should not differ dramatically from state to state. With the understanding that reporting thresholds could affect the overall crash rates, this phenomenon should have little effect on the comparison of rates between ABS- and non-ABS-equipped light trucks. The results, in fact, did not appear to contradict this assumption, i.e., when the state results were examined in pairs, there were no pairs in which there were statistically significant results for the impact of ABS in opposite directions under the same circumstances. Therefore, the state ABS estimated coefficients were statistically combined to form a single estimate, the *common log odds ratio*, for the same level of SYSTEM, RESPONSE and SURFACE, using statistical methods described in Fleiss<sup>6</sup>. These results are displayed in Table 2 and represent crashes of all severities in the four states.

The coefficients in Table 2 can be translated into the percentage change in the expected number of relevant crashes in the following way:

$$\text{Expected percentage change} = 100 * [\exp(\text{ABS coefficient}) - 1] \quad (1)$$

The justification for this formulation is as follows:

Assume a group of vehicles, without ABS, have  $N$  crashes of which  $p_0 N$  are relevant and  $(1-p_0)N$  are nonrelevant. With ABS there will still be  $(1-p_0)N$  nonrelevant crashes. There will now be  $R$  relevant crashes where  $R/[R+(1-p_0)N] = p_1$ , i.e.,  $R = [p_1/(1-p_1)]N(1-p_0)$  since  $p_1$  is the new proportion of relevant crashes. But  $p_0$  and  $p_1$  are related by:

$$[p_1/(1-p_1)]/[p_0/(1-p_0)] = \exp(\text{ABS coefficient}). \quad (2)$$

It follows that the expected percentage change in the number of relevant crashes due to ABS is:

$$100 * (R - p_0 N) / (p_0 N), \quad \text{or} \quad 100 * [\exp(\text{coefficient}) - 1]. \quad (3)$$

The proportion of ABS-relevant crashes could conceivably change in two different ways: ABS-relevant crashes could be prevented or ABS-relevant crashes could be replaced by ABS-nonrelevant crashes. The assumption is being made that the presence of ABS has the potential to prevent the relevant crashes. This is probably generally true when the response is collision with another vehicle or fixed object. In the case of rollover, it is possible that the crash would still take place but be mitigated in the presence of ABS, that is, would become a nonrollover crash. However, since the proportion of rollover crashes is small, in equation (2),  $1-p_0$  and  $1-p_1$  are approximately 1 and we still obtain, approximately,  $p_1/p_0 = \exp(\text{ABS coefficient})$  so that  $(p_1 - p_0)/p_0 = \exp(\text{ABS coefficient}) - 1$ .

Replacing the ABS coefficient,  $c$ , in (1) with  $c \pm 1.96 * (\text{standard error of } c)$  results in 95 percent confidence limits for the expected percentage change in relevant crashes. The results are displayed in Table 3.

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<sup>6</sup> Fleiss. *Statistical Methods for Rates and Proportions*, John Wiley & Sons, Inc., 1981.

**TABLE 2**  
**Combined ABS Coefficients and Standard Errors**  
**for All Crashes**

SYSTEM	CRASH TYPE	SURFACE CONDITION	ABS COEFF	STANDARD ERROR	CRASH EFFECT
AWAL	ROLL	Bad	- 0.34947	0.20070	NS
AWAL	ROLL	Good	- 0.66166	0.31512	DECREASE
AWAL	ROR	Bad	- 0.47311	0.16517	DECREASE
AWAL	ROR	Good	- 0.08959	0.16371	NS
AWAL	SIDE	Bad	- 0.61889	0.28569	DECREASE
AWAL	SIDE	Good	- 0.02120	0.24533	NS
AWAL	FRONT	Bad	- 0.23146	0.08515	DECREASE
AWAL	FRONT	Good	0.13343	0.05444	INCREASE
RWAL	ROLL	Bad	- 0.36482	0.04328	DECREASE
RWAL	ROLL	Good	- 0.60914	0.05220	DECREASE
RWAL	ROR	Bad	- 0.03316	0.03040	NS
RWAL	ROR	Good	- 0.00240	0.03110	NS
RWAL	SIDE	Bad	- 0.34677	0.04901	DECREASE
RWAL	SIDE	Good	- 0.16012	0.05100	DECREASE
RWAL	FRONT	Bad	0.14413	0.02210	INCREASE
RWAL	FRONT	Good	0.09445	0.01370	INCREASE

**LEGEND:**

ALL CRASHES

= Fatal and Nonfatal

RWAL

= LTVs equipped w/RWAL

AWAL

= LTVs equipped w/AWAL

ROLL

= Rollover Crashes

SIDE

= Side impact Crashes with parked vehicles or fixed objects.

FRONT

= Frontal impact Crashes with another vehicle in transport.

ROR

= Frontal impact Crashes with parked vehicles or fixed objects.

NS

= Not significant

**TABLE 3**

**Estimated Percentage Changes in Crash Types for ABS-Equipped  
Vehicles With 95 Percent Confidence Bounds**

Fatal Crash	System Type	Crash Type	Surface Condition	Percentage Change	Lower Bound	Upper Bound
N	AWAL	ROLL	Bad	- 29	- 52	+ 4
N	AWAL	ROLL	Good	<u>- 48</u>	- 72	- 4
N	AWAL	ROR	Bad	<u>- 38</u>	- 55	- 14
N	AWAL	ROR	Good	- 9	- 34	+ 26
N	AWAL	SIDE	Bad	<u>- 46</u>	- 69	- 6
N	AWAL	SIDE	Good	- 2	- 39	+ 58
N	AWAL	FRONT	Bad	<u>- 21</u>	- 33	- 6
N	AWAL	FRONT	Good	<u>+ 14</u>	+ 3	+ 27
N	RWAL	ROLL	Bad	<u>- 31</u>	- 36	- 24
N	RWAL	ROLL	Good	<u>- 46</u>	- 51	- 40
N	RWAL	ROR	Bad	- 3	- 9	+ 3
N	RWAL	ROR	Good	0	- 6	+ 6
N	RWAL	SIDE	Bad	<u>- 29</u>	- 36	- 22
N	RWAL	SIDE	Good	<u>- 15</u>	- 23	- 6
N	RWAL	FRONT	Bad	<u>+ 16</u>	+ 11	+ 21
N	RWAL	FRONT	Good	<u>+ 10</u>	+ 7	+ 13
Y	AWAL	ROLL	Bad	+ 4	- 62	+187
Y	AWAL	ROLL	Good	+ 17	- 25	+ 82
Y	AWAL	ROR	Bad	- 70	- 93	+ 31
Y	AWAL	ROR	Good	0	- 37	+ 58
Y	AWAL	SIDE	Bad	- 67	- 96	+152
Y	AWAL	SIDE	Good	+ 84	- 10	+278
Y	AWAL	FRONT	Bad	- 37	- 67	+ 18
Y	AWAL	FRONT	Good	- 10	- 33	+ 19
Y	RWAL	ROLL	Bad	+ 8	- 24	+ 54
Y	RWAL	ROLL	Good	+ 7	- 14	+ 32
Y	RWAL	ROR	Bad	+ 16	- 14	+ 57
Y	RWAL	ROR	Good	+ 10	- 6	+ 28
Y	RWAL	SIDE	Bad	+ 23	- 17	+ 82
Y	RWAL	SIDE	Good	+ 1	- 25	+ 37
Y	RWAL	FRONT	Bad	<u>+ 48</u>	+ 24	+ 77
Y	RWAL	FRONT	Good	<u>+ 27</u>	+ 16	+ 40

The top two sections of Table 3 present findings for nonfatal crashes. There are a number of statistically significant changes (shown in boldface and underlined in the table) associated with both AWAL and RWAL. Significant decreases were found for RWAL LTVs in nonfatal rollover crashes on both good and bad road surfaces, and for AWAL LTVs on good surfaces (however, the reduction for AWAL on bad surfaces just failed to reach statistical significance). Significant reductions also were found for RWAL LTVs in nonfatal side-impact with fixed object crashes on both good and bad surfaces, and for AWAL LTVs on bad surfaces. Lastly, RWAL LTVs exhibited significant increases in fatal frontal crashes with another motor vehicle in transport on both good and bad road surfaces, while AWAL LTVs experienced a significant increase in these nonfatal crashes on good surfaces, but a significant decrease on bad road surfaces. In general, LTVs equipped with ABS experienced significant reductions in most directional control-related crashes (that is, rollover and side-impact fixed object crashes) on bad road surfaces, but experienced significant increases in frontal crashes with another motor vehicle in transport on good road surfaces.

Unfortunately, the reductions observed for nonfatal crashes were not found for fatal crashes. The two statistically significant changes for fatal crashes were increases in fatal frontal crashes with another motor vehicle in transport for RWAL-equipped LTVs on both good and bad road surfaces. While some rather large reductions were found for AWAL-equipped vehicles, the sample sizes available for analysis were somewhat limited by the small numbers of vehicles with this equipment in the on-road LTV population. Thus, conclusions related to AWAL should be considered preliminary.

Does the impact of the presence of ABS differ on "good" road surfaces vs. "bad" road surfaces? To answer this question, observe that for each combination of the 2 values of FATAL, the 4 values of RESPONSE and the 3 values of VEHICLE, Table 2 displays two estimates for the ABS coefficient, one for "good" surfaces (i.e., favorable road conditions; dry, paved road surfaces that are free of debris) and one for "bad" surfaces (i.e., unfavorable road conditions; wet, icy, snowy, gravel or otherwise unpaved). For each of these estimates, there is an estimated standard error. Since these estimates are independent, it is straightforward to test if their difference is significantly different from 0 at  $p = 0.05$ . If it is not, they can be combined, again using the method described in Fleiss. These results are displayed in Table 4. In Table 4, the PERCENT CHANGE is the point estimate. The last column of Table 4 indicates if the ABS effect is significantly different from zero.

**TABLE 4****Estimated Percentage Change in Response Crashes  
in ABS Vehicles, When Surfaces Can Be Combined**

Fatal Crash	System Type	Crash Type	Percentage Change	Statistically Significant
N	AWAL	ROLL	- 36	Yes
N	AWAL	ROR	- 24	Yes
N	AWAL	SIDE	- 24	
N	RWAL	ROR	- 2	
N	RWAL	FRONT	+11	Yes
Y	AWAL	ROLL	+15	
Y	AWAL	ROR	- 10	
Y	AWAL	SIDE	+52	
Y	AWAL	FRONT	- 16	
Y	RWAL	ROLL	+ 7	
Y	RWAL	ROR	+11	
Y	RWAL	SIDE	+ 9	
Y	RWAL	FRONT	+32	Yes

Table 5 summarizes the statistically significant expected percentage changes with ABS, combining surfaces where it is valid to do so and presenting effects separately by surface condition where they are significantly different. Confidence limits are presented to give a sense of the different levels of precision.

**TABLE 5****Summary of Statistically Significant Effects of ABS**

Fatal Crash	System Type	Crash Type	Surface Condition	Percentage Change	Lower Bound	Upper Bound
N	AWAL	ROLL	BOTH	- 36	- 54	- 10
N	AWAL	ROR	BOTH	- 24	- 40	- 5
N	AWAL	FRONT	BAD	- 21	- 33	- 6
N	AWAL	FRONT	GOOD	+14	+ 3	+27
N	RWAL	ROLL	BAD	- 31	- 36	- 24
N	RWAL	ROLL	GOOD	- 46	- 51	- 40
N	RWAL	SIDE	BAD	- 29	- 36	- 22
N	RWAL	SIDE	GOOD	- 15	- 23	- 6
N	RWAL	FRONT	BOTH	+11	+ 9	+14
Y	RWAL	FRONT	BOTH	+32	+21	+43

**LEGEND:**

Y = Fatal Crashes

N = All Crashes

RWAL = LTVs equipped w/RWAL

AWAL = LTVs equipped w/AWAL

ROLL = Rollover Crashes

SIDE = Side impact Crashes with parked vehicles or fixed objects.

FRONT = Frontal impact Crashes with another motor vehicle in transport.

ROR = Frontal impact Crashes with parked vehicles or fixed objects.

**DISCUSSION**

For fatal crashes, the presence of ABS appears to be associated with a net increase in fatal crashes. Most of this increase is associated with the increase in LTV fatal frontal crashes with another motor vehicle in transport. Small, nonsignificant increases in fatal crashes involving RWAL-equipped LTVs were found for single-vehicle rollovers, run-off-road and side-impact with fixed object crashes.

The sample size of available LTVs with AWAL was quite small, as is their representation in the on-road fleet. No significant changes were noted for the various ABS-relevant fatal crash types, with a predicted reduction (nonsignificant) of fatal crashes associated with these vehicles. A review of Table 3 shows that on bad road surfaces, AWAL-equipped LTVs

experienced rather large reductions in run off the road frontal fatal crashes, side-impact fixed object fatal crashes, and frontal fatal crashes with another motor vehicle in transport. Thus, as the prevalence of AWAL LTVs increases, these reductions may become statistically significant.

For nonfatal crashes, the presence of ABS appears to be associated with an increase in nonfatal crashes, consisting of an increase associated with RWAL vehicles, and a decrease associated with the presence of AWAL. Most of this increase consists of a significant increase in RWAL LTV crashes involving frontal impacts with another motor vehicle, which comprise a large proportion of all crashes. This was offset by significant decreases in rollover crashes and side-impact fixed object crashes; both types of crashes are much less frequent than "did not stop in time" crashes.

These findings are somewhat similar to the findings of Kahane (1993) on the effectiveness of RWAL for light trucks. Kahane found that:

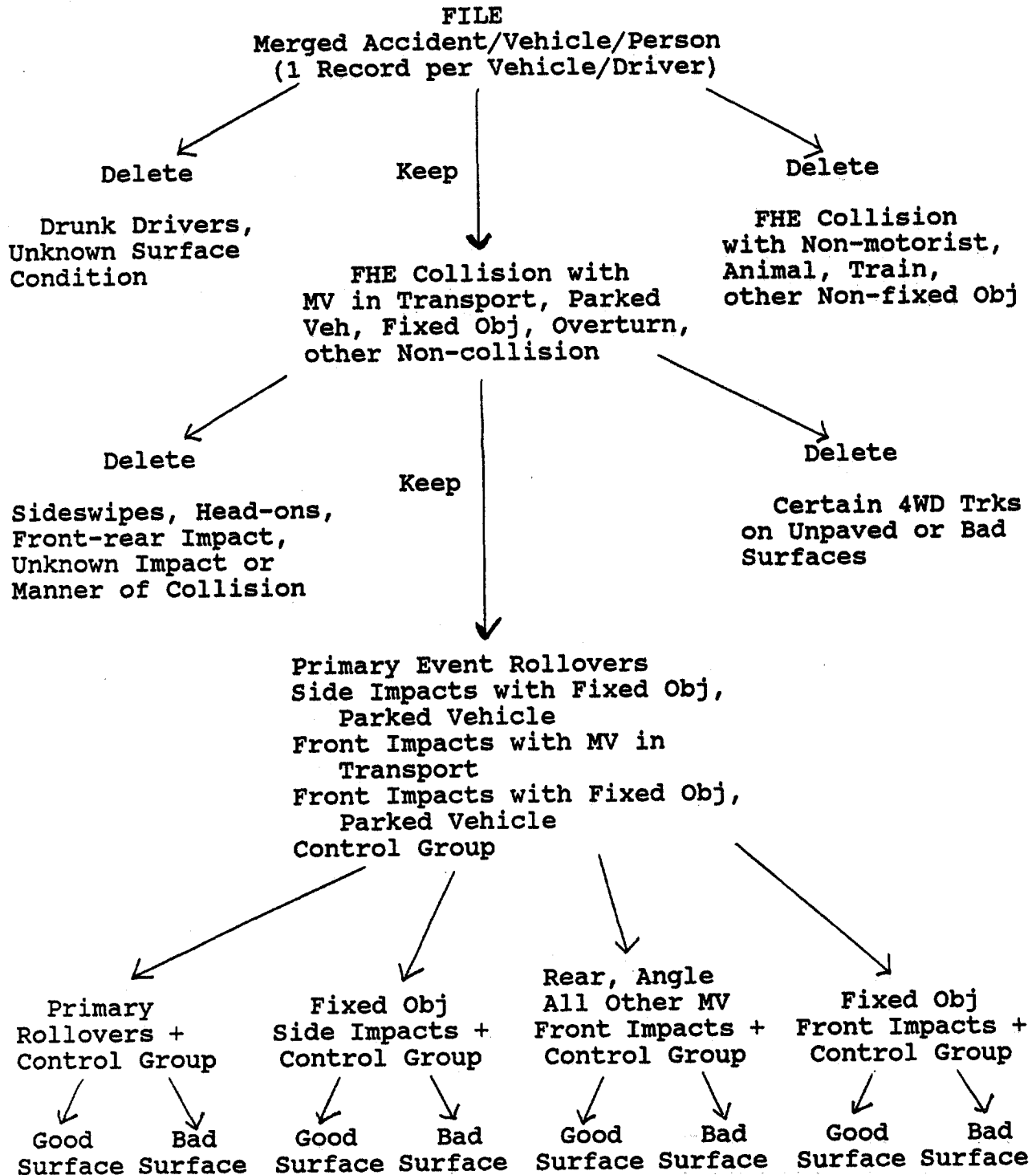
- o RWAL reduces the risk of nonfatal run-off-road crashes, for any type of road condition, for almost every type of light truck. The most sizeable reduction in these crashes comes from a reduction in nonfatal rollover crashes, similar to the findings in this study.
- o RWAL has little or no effect on nonfatal multivehicle crashes. Similarly, no effect on front impact crashes with another motor vehicle (FRONT) was found in this study.
- o The effect of RWAL in fatal multivehicle crashes and fatal run-off-road crashes is uncertain. In this study, the findings were uncertain as well, i.e., little or no effect in some crashes, significant increases in others.

Overall, the findings here should be carefully considered, in light of several issues that could influence the determination of effectiveness of ABS for LTVs. Results of effectiveness of ABS could change, as more vehicles enter the fleet with ABS.

## **APPENDIX A**

### **Schematic Diagram for Separating Databases Into ABS-relevant Crashes and non-ABS-relevant Crashes**







## **APPENDIX B**

### **Numbers of Light Trucks and Vans Used in Analysis of ABS-relevant Crashes and non-ABS-relevant Crashes**



**Numbers of Light Trucks and Vans Used  
in Analysis for ABS-relevant Crashes and  
non-ABS-relevant (Control) Crashes\***

**ROLLOVER CRASHES**

Vehicle Type	Data Source				
	FARS	Florida	Maryland	Michigan	Missouri
Sport/Utility Vehicles	348	341	21	1181	308
Pickups	465	704	40	2777	781
Vans	122	110	8	474	94
TOTAL	1039	1250	73	4563	1227
# ABS Equipped	441	351	50	1283	342
% ABS	42.4%	28.1%	68.5%	28.1%	27.9%

**SIDE DAMAGE WITH FIXED OBJECT/  
PARKED VEHICLE CRASHES**

Vehicle Type	Data Source				
	FARS	Florida	Maryland	Michigan	Missouri
Sport/Utility Vehicles	36	151	160	416	116
Pickups	200	500	444	1745	625
Vans	25	129	148	377	134
TOTAL	399	1164	1225	2930	1115
# ABS Equipped	167	372	392	904	335
% ABS	41.9%	32.0%	32.0%	30.9%	30.0%

**FRONT DAMAGE WITH MOTOR VEHICLE  
IN TRANSPORT CRASHES**

Vehicle Type	Data Source				
	FARS	Florida	Maryland	Michigan	Missouri
<b>Sport/Utility Vehicles</b>	<b>444</b>	<b>4320</b>	<b>963</b>	<b>9643</b>	<b>2189</b>
<b>Pickups</b>	<b>1658</b>	<b>13162</b>	<b>2498</b>	<b>32999</b>	<b>9525</b>
<b>Vans</b>	<b>279</b>	<b>4472</b>	<b>764</b>	<b>9370</b>	<b>1704</b>
<b>TOTAL</b>	<b>2815</b>	<b>32039</b>	<b>6060</b>	<b>62837</b>	<b>26836</b>
<b># ABS Equipped</b>	<b>1252</b>	<b>11356</b>	<b>2111</b>	<b>23085</b>	<b>5887</b>
<b>% ABS</b>	<b>44.5%</b>	<b>35.4%</b>	<b>34.8%</b>	<b>36.7%</b>	<b>21.9%</b>

**FRONT DAMAGE WITH FIXED OBJECT/  
PARKED VEHICLE CRASHES**

Vehicle Type	Data Source				
	FARS	Florida	Maryland	Michigan	Missouri
<b>Sport/Utility Vehicles</b>	<b>195</b>	<b>467</b>	<b>192</b>	<b>1426</b>	<b>515</b>
<b>Pickups</b>	<b>725</b>	<b>1635</b>	<b>564</b>	<b>5771</b>	<b>2392</b>
<b>Vans</b>	<b>118</b>	<b>390</b>	<b>128</b>	<b>1135</b>	<b>308</b>
<b>TOTAL</b>	<b>1327</b>	<b>3563</b>	<b>1236</b>	<b>9628</b>	<b>3731</b>
<b># ABS Equipped</b>	<b>518</b>	<b>1260</b>	<b>435</b>	<b>3404</b>	<b>1308</b>
<b>% ABS</b>	<b>39.0%</b>	<b>35.4%</b>	<b>35.2%</b>	<b>35.4%</b>	<b>35.1%</b>

## CONTROL GROUP CRASHES

Vehicle Type	Data Source				
	FARS	Florida	Maryland	Michigan	Missouri
<b>Sport/Utility Vehicles</b>	<b>406</b>	<b>4777</b>	<b>1566</b>	<b>9641</b>	<b>2664</b>
<b>Pickups</b>	<b>1496</b>	<b>14335</b>	<b>4422</b>	<b>36848</b>	<b>12041</b>
<b>Vans</b>	<b>293</b>	<b>5304</b>	<b>1370</b>	<b>11403</b>	<b>2251</b>
<b>TOTAL</b>	<b>2895</b>	<b>37573</b>	<b>11257</b>	<b>70282</b>	<b>20634</b>
<b># ABS Equipped</b>	<b>1093</b>	<b>12994</b>	<b>3764</b>	<b>25659</b>	<b>20634</b>
<b>% ABS</b>	<b>37.8%</b>	<b>34.6%</b>	<b>33.4%</b>	<b>36.5%</b>	<b>35.3%</b>

\* Actual number of vehicles will vary for each logistic regression as observations with missing values are deleted from the regression.



## **APPENDIX C**

### **List of Light Trucks and Vans Equipped w/ABS and Comparable Vehicles w/o ABS**



# **List of Light Truck and Vans with and without ABS**

<b>With ABS</b>		<b>Without ABS</b>	
<b>Vehicle Make/Model</b>	<b>Model Year(s)</b>	<b>Vehicle Make/Model</b>	<b>Model Year(s)</b>
Dodge Dakota	89-94	Dodge Dakota	87
Dodge Ram Van	90-92	Dodge Ram Van	87-89
Dodge Ram Wagon	90-92	Dodge Ram Wagon	87-89
Dodge D-Series Pickup	88-92	Dodge D-Series Pickup	83-87
Dodge W-Series Pickup	89-92	Dodge W-Series Pickup	84-87
Ford Ranger	89-92	Ford Ranger	84-88
Ford F-Series Pickup	87-92	Ford F-Series Pickup	83-86
Ford E-Series Van	90-92	Ford E-Series Van	87-89
Ford Bronco	87-90	Ford Bronco	83-86
Ford Bronco II	87-90	Ford Bronco II	83-86
Ford Aerostar	90-92	Ford Aerostar	85-89
GM C/R/K/V-10/15 Pickup	88-92	GM C/R/K/V/-10/15 Pickup	83-87
GM S/T-10/15 Pickup	89-92	GM S/T-10/15 Pickup	84-88
GM G-Series Van	90-92	GM G-Series Van	84-89
GM K/V-10/15 Blazer/Jimmy	90-91	GM K/V-10/15 Blazer/Jimmy	84-89
GM K/V-10/15 Blazer/Jimmy	92*		
GM S/T-10/15 Blazer/Jimmy	89-91	GM S/T-10/15 Blazer/Jimmy	84-88

\* All Wheel Antilock Brakes (AWAL)

\*\* Four Door Cab Model has AWAL

**List of Light Truck and Vans with and without ABS - Continued**

<b>With ABS</b>		<b>Without ABS</b>	
<b>Vehicle Make/Model</b>	<b>Model Year(s)</b>	<b>Vehicle Make/Model</b>	<b>Model Year(s)</b>
<b>GM S/T-10/15 Blazer/Jimmy</b>	<b>91**</b>		
<b>GM S/T-10/15 Blazer/Jimmy</b>	<b>92*</b>		
<b>GM Astrovan/Safari</b>	<b>89</b>	<b>GM Astrovan/Safari</b>	<b>85-88</b>
<b>Chevy Astrovan</b>	<b>90-92* 92</b>		

\* All Wheel Antilock Brakes (AWAL)

\*\* Foor Door Cab Model has AWAL







